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Executive Summary
What-if analysis has been widely implemented as a key feature in computer-based decision aids and decision support systems (DSS) to support decision making activities. However, its effects on decision making have not been fully understood. Research investigating its effectiveness is limited and results to date suggest mixed findings.

As a DSS is typically interactive, we suggest that the effects of what-if analysis in a DSS should be studied in conjunction with the user interface of the system. Previous research suggests that different input and output interfaces will result in different cognitive loading in human information processing, thus affecting the decision making process. With the evolution of interface technology, new forms of input interfaces and enhanced presentation formats involving graphics and direct manipulation of screen objects have become available at reasonable cost. It would be useful to study their effectiveness in the context of DSS use.

This research attempts to study the effects of what-if analysis and user interface type on decision making. In particular, three different user interface types were examined: (i) Numeric input with tabular presentation (ii) Numeric input with graphical presentation, and (iii) Graphical input with graphical presentation. A controlled experiment was conducted in the context of an aggregate production planning problem. Subjects assumed the role of a production manager and were required to make decisions on production and workforce levels over a series of 16 periods. Each subject was assisted by a computer decision aid either with or without what-if analysis function and was designed with one of the three user interface types. Effectiveness of the decision aids was measured in both quantitative and qualitative terms. The Group Embedded Figures Test (GEFT) score (a measure of cognitive style) was used as a covariate to control for the possible effect of differences in cognitive styles on decision making, thus providing greater control over the experiment.

Results showed that what-if analysis improved decision performance significantly but it required longer decision time. User interface type also had significant effect on decision performance. In particular, the user interface type involving graphical input and graphical presentation resulted in significantly better performance. In addition, there was a significant interaction effect between what-if analysis and user interface type on decision performance. This suggests that decision makers and DSS designers need to work closely together in choosing the appropriate kinds of features and user interfaces to be built into the DSS. The results of this study also encourages decision makers and DSS designers to take advantage of using direct manipulation and object-orientation in user interface design of a DSS. While the effects on other measures such as learning, decision confidence, perceived usefulness and perceived ease of use were not statistically significant, most of the results were in the hypothesized direction. In the long run, our understanding of a complex and wide ranging topic such as what-if analysis and user interface will only be achieved by cumulative research efforts.

KEYWORDS: User Interface, What-if Analysis, Decision Support Systems, Direct Manipulation, Decision Making

Introduction

There have been impressive advances in computer technology (both hardware and software) for supporting decision making. Models, enhanced functions and analysis methods have been incorporated into decision support systems (DSS) and more user-friendly interfaces have been designed to make them easy to use.

One common feature of DSS is the use of what-if or sensitivity analysis which allows the decision maker to explore the effects of different values of decision variables/parameters on decision outcome. In most cases, the decision maker is allowed to manipulate the values of one or more decision variables/parameters involved and the corresponding decision outcome will be generated by the DSS based on some underlying quantitative model(s). By obtaining the outcome feedback, the decision maker is able to learn about the relationship between decision variables and the decision outcome before making the actual decision.

Research shows that both DSS managers and practitioners have rated what-if analysis as the most important feature of a DSS (Mahmood and Sniezek 1989). Despite the popularity of what-if analysis, research investigating its effectiveness is limited and results to date suggest mixed findings.

Since a DSS is typically interactive in nature, its effectiveness is likely to be impacted greatly by its user interface, especially from the user's perspective (Sprague 1980). As technology evolves, user interface design has broken away from the constraints of the teletype and keyboard designs. New forms of input interfaces and enhanced presentation formats involving graphics and direct manipulation of screen objects have become available at reasonable cost (Shneiderman 1988). It would be useful to study the effectiveness of this new forms of user interface in the context of decision support.

Research so far has focused on input and output interfaces separately (Dos Santos and Holsapple 1989). Much research effort has been dedicated to comparing tabular and graphic presentations but the results so far are inconclusive (Benbasat, Dexter and Todd 1986, Dickson, DeSanctis and McBride 1986, Jarvenpaa and Dickson 1988). As a user interface is constituted of both the input and output interfaces, it is important to study the two together so that the interrelationship between the two can be examined more explicitly.

This research attempts to study the effects of what-if analysis together with the use of different user interface types in a direct manipulation environment on decision making. In particular, three user interface types were examined: (i) Numeric input (data input by typing) with tabular presentation, (ii) Numeric input with graphical presentation, and (iii) Graphical input (data input by direct manipulation on graphical objects) with graphical presentation. Specifically the following research questions are addressed: (a) Does what-if analysis improve decision performance? (b) Among the three user interface types being studied, which one is the most superior in supporting decision making? (c) Is there any interaction effect between the use of what-if analysis and the type of interfaces used? Both quantitative and qualitative measures were used.

Background and previous research

What-if analysis or sensitivity analysis is a quantitative analysis which provides an assessment of tradeoffs to find out what combinations of decision variables / parameters are best in which situation (Schneider 1988). What-if analysis simulates the decision outcome based on the values of decision variables and some underlying models. Several researchers have proposed that this is one of the more important features of a DSS (Keen 1981, Alavi 1982, Sprague and Carlson 1982).

A review of literature in decision sciences, human decision process, and related disciplines suggests that what-if analysis may support decision making in four respects: (i) bring structure to less-structured problems, (ii) lead to consideration of more alternatives, (iii) increase decision confidence, and (iv) provide feedback and learning.

Although what-if analysis has been widely used to support decision-making activities, its effects on decision making have not been fully understood. Research investigating the effectiveness of what-if analysis is limited and findings from previous studies are mixed and inconclusive. Some researches

have suggested that what-if analysis improved decision performance (Benbasat and Dexter 1982, Sharda, Barr and McDonnell 1988); some have reported that what-if analysis had no significant effects on decision performance (Fripp 1985, Goslar, Green and Hughes 1986); others have shown that decision makers supported by what-if analysis capability performed worse than those unaided and that what-if analysis may even lead to overconfidence and 'illusion of control' among decision makers without improving decision quality or performance (Kottemann and Remus 1987, 1991, and 1992, Davis, Kottemann and Remus 1991).

While these mixed findings may partly be attributable to the differences in decision problems, task environments, factors considered, and measurements used in different studies, the differences in the user interface and the quality of the decision aids used could also be a plausible explanation. The user interface of a DSS refers to those attributes of a DSS that define the interaction between the user and the DSS (Dos Santos and Holsapple 1989). It has been argued that the user interface is the most important element of a DSS from the user's perspective and that the effectiveness of a DSS is largely determined by the user interface (Benbasat,Dexter and Masulis 1981, Sprague and Carlson 1982).

Norman's (1986) cognitive model for interacting with a computer system suggested that the forms of input and output of a computer have a close relationship on the cognitive loading in human information processing. Cognitive loading involves the effort of a computer user to 'translate' the meaning of input expression he / she wants to communicate with the computer into actual forms of input, and to interpret the actual forms of output from the computer. Based on Norman's model, Hutchins, Hollan and Norman (1986) suggested that a good input and output interface design will help to reduce cognitive loading, thus improve the decision making process.

The discussion of user interface can be further subdivided into the input interface and the output interface. The input interface provides the means for users to enter required data as well as to translate his or her intentions to actions accepted by the computer systems. Traditional interface styles emerged from a teletype or a text-oriented view of task. Common examples are menu selection, form fill-in, command language, and natural language (Shneiderman 1988). They are linguistic, verbal and procedural in nature (Te'eni 1990). As technology in bit-mapped high resolution displays becomes less expensive, user interface design is breaking away from the constraints of teletype and keyboard designs and moving towards screen-oriented, form-oriented, visual and graphical design approaches with pointing devices, e.g., direct manipulation or graphical user interface. The concept of direct manipulation or graphical user interface helps in creating a visual representation of the 'world of action' that includes selectable displays of the objects and actions of interest, eg buttons, icons, etc. This abstraction of reality gives users a feeling of naturalness and direct engagement with the semantic objects of their goals and intentions of actions, resulting presumably in less cognitive effort and greater user satisfaction (Hutchins, Hollan and Norman 1986, Shneiderman 1988).

Not only action commands can be entered graphically by clicking buttons or pointing directly over a menu bar with the mouse but numeric data input can also be done through direct manipulation. For example, instead of typing in the values of decision variables through the keyboard, users can now enter the values by manipulating the height of a bar in a bar chart or the position of a point in a line graph. This form of input is argued to give the user a direct feel for the values in relation to each other, especially when all data and information are displayed in the same graphical format.

The output interface of a DSS provides the means to communicate information from the system to the user. It supports decision making by providing necessary information for decision making as well as providing outcome feedback on decision made. Tabular and graphical forms of data presentation are the two most basic and dominant forms of presentation in DSS. A good deal of DSS research has compared the effectiveness of tabular presentations with graphical ones (Blocher, Moffie and Zmud 1986, DeSanctis and Jarvenpaa 1989, Carey and White 1991). Although many dramatic claims have been made about the benefits of computer graphics in supporting various decision-making activities, this is not totally supported by previous research findings (Benbasat, Dexter and Todd 1986, Jarvenpaa and Dickson 1988). Nevertheless, researchers generally suggest that graphics are suitable for summarizing a large amount of data, forecasting activities, comparing points and patterns of different variables, perceiving relationships among the data, and when there is a time constraint; while tables are suitable for data value reading and simple data retrieval (Ghani 1981, Jarvenpaa and Dickson 1988, Dickson, DeSanctis and McBride 1986, Benbasat, Dexter and Todd 1986). As

computing technology moves toward a graphical and direct manipulative user interface environment, it is necessary to shift our research focus to the way that this new kind of input and output interfaces work together to support decision making activities.

Research Framework

As suggested in the literature,, the effectiveness of a DSS is not only dependent on its characteristics and features available, but is also determined by the characteristics of the decision maker and the task. By considering these factors, a conceptual model shown in Figure 1 was constructed for this study.

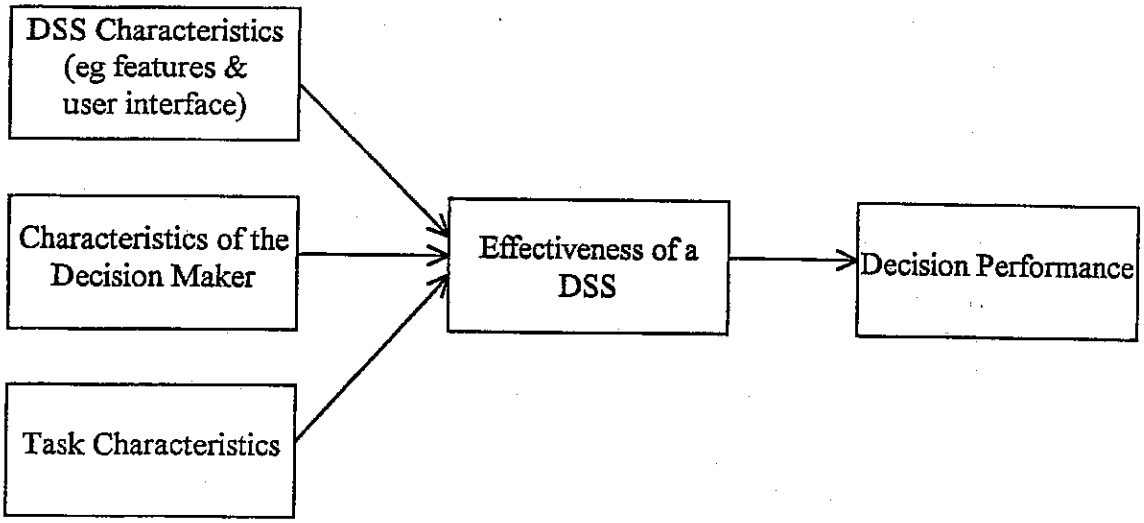

Figure 1 A Conceptual Model for Studying the Effectiveness of a DSS

In this study, we focused on two DSS characteristics, namely, what-if analysis and user interface type, which served as two independent constructs. Concerning the possible effects of the characteristics of decision makers, the cognitive style of decision makers was measured by the Group Embedded Figures Test (GEFT) of Witkin et al. (1971) which served as a covariate to enhance the control of our study, while other individual differences were controlled through randomization. In this study, variables associated with the task and the task environment were controlled via the use of a standard aggregate production planning problem, a problem based on Holt et al. (1960). The effectiveness of the DSS and the decision performance were the dependent variables in this study and were measured in terms of production cost, decision time, learning, decision confidence, perceived usefulness, and perceived ease of use.

Hypotheses

Hypotheses are proposed to examine the main and interaction effects of what-if analysis and user interface type on several aspects of decision making. Related literature suggests that what-if analysis supports decision making by (i) bring structure to less-structured problems, (ii) lead to consideration of more alternatives, (iii) increase decision confidence, and (iv) provide feedback and learning. In addition, we propose that the learning effect will be particularly significant in the early stage of the decision task when the decision maker is not familiar with the problem and outcome feedback from what-if analysis help identify interrelationship between decision variables and decision outcome. As a result, we have the following hypotheses pertaining to the effects of what-if analysis:

H1 : Decision makers using what-if analysis will show a better decision performance than decision makers without what-if analysis.

H2: Decision makers with what-if analysis will have a faster learning rate than decision makers without what-if analysis at the early stage.

H3: Decision makers using what-if analysis will take more time to make decisions than decision makers without what-if analysis.

H4: Decision makers with what-if analysis will have greater confidence in their decisions than decision makers without what-if analysis.

H5: Decision makers using decision aids with what-if analysis will perceive it to be more useful when compared to those using decision aids without what-if analysis.

Decision makers need to understand the interrelationships between decision variables and the decision outcome before good decisions can be made. This often involves detection of the underlying model, comparison of data patterns, prediction of trends, summarization and interpretation of a vast amount of data. Graph theorists have argued that graphical presentations have the advantage over tabular presentations in these kinds of information interpretation tasks (Tufte 1983, Cleveland 1985). The literature on decision making also generally suggests that graphical presentations perform better in summarizing data, comparing points and patterns of different variables, and detecting trends over time (Jarvenpaa and Dickson 1988). Therefore, we expect in our study that the user interfaces using graphical presentation would help decision makers to better understand the problem, increase their decision confidence, and lead to better decision performance and greater user satisfaction. When comparing the two interface types which used graphical presentations in this study (one used numeric input whereas the other used graphical input), we propose that the one with graphical input would lead to better decisions than that with numeric input. This is because when data input is also made graphically (by direct manipulation) in the same graphical context, cognitive effort and errors in information interpretation and processing will be further reduced. Thus, we have the following hypotheses pertaining to the effects of user interface type:

H6(a), (b), (c): Decision makers will perform better when using the interface with graphical input and graphical presentation (GI, GP) as compared to those using the interface with numeric input and graphical presentation (NI, GP) or numeric input and tabular presentation (NI, TP).
Performance: P(GI, GP) > P(NI, GP) > P(NI, TP)

H7(a), (b), (c): Decision makers will have a faster learning rate when using (GI, GP) as compared to those using (NI, GP) or (NI, TP).
Learning: L(GI,GP) > L(NI,GP) > L(NI, TP)

H8(a), (b), (c): Decision makers will take less decision time when using (GI, GP) as compared to those using (NI, GP) or (NI, TP).
Decision Time: T(GI,GP) < T(NI,GP) < T(NI, TP)

H9(a), (b), (c): Decision makers will have greater decision confidence when using (GI, GP) as compared to those using (NI, GP) or (NI, TP).
Decision Confidence: C(GI, GP) > C(NI, GP) > C(NI, TP)

H10(a), (b), (c): The decision aid will be perceived to be more useful when using (GI, GP) as compared to those using (NI, GP) or (NI, TP).
Perceived Usefulness: PU(GI,GP) > PU(NI,GP) > PU(NI, TP)

H11(a), (b), (c): The decision aid will be perceived to be easier to use when using (GI, GP) as compared to those using (NI, GP) or (NI, TP).
Perceived Ease of Use: PE(GI,GP) > PE(NI,GP) > PE(NI, TP)

Apart from the individual effects of the two factors on decision making, we are also interested in the effects when the two factors operate together, i.e. the interaction effects. We hypothesized that the effect of what-if analysis on decision making will be further enhanced when accompanied by the appropriate user interface type. Building on the previous hypotheses, we have the following additional hypotheses pertaining to interaction effects:

H12 : There will be a significant interaction effect between the two main factors on production cost.

H13 : There will be a significant interaction effect between the two main factors on learning rate in the early phase.

H14 : There will be a significant interaction effect between the two main factors on decision time.

H15 : There will be a significant interaction effect between the two main factors on decision confidence.

H16 : There will be a significant interaction effect between the two main factors on perceived usefulness.

Method

Experimental Design

A controlled laboratory experiment was conducted in the context of an aggregate production planning problem. A 2x3 factorial design was used, forming six treatment groups (as shown in Table 1).

		User Interface Type		
		Numeric Input with Tabular Presentation	Numeric Input with Graphical Presentation	Graphical Input with Graphical Presentation
What-if Factor	Without What-if Analysis	18 subjects	17 subjects	17 subjects
	With What-if Analysis	18 subjects	17 subjects	19 subjects

Table 1 A 2x3 Factorial Design

The Experimental Task

The aggregate production planning problem was based on Holt et al. (1960). This is a decision problem that has been used in a number of previous studies addressing similar and related research questions (eg Moskowitz 1972, Kottemann and Remus 1987, Davis, Kottemann and Remus 1991). In this problem, a decision maker faces uncertain future demand and must choose a production level and a workforce level over a series of time periods (16 periods in this study). The objective is to minimize the cumulative average cost of production. The cost of production in a particular period is the sum of four cost components: (i) Regular Payroll Cost, (ii) Hiring and Layoff Cost, (iii) Overtime/Idletime Cost, and (iv) Cost for non-optimal ending inventory.

Based on Holt et al. (1960), linear decision rules for production and workforce levels in each period can be obtained. Costs obtained based on these decision rules were used as the bases when comparing the subjects' performance and learning.

The Decision Aids

Computer decision aids were developed to simulate the task and incorporate the what-if analysis functionality and different user interface types according to the six treatments. Information was displayed in spreadsheet format for treatments using tabular presentations; line graphs and bar charts were used for treatments using graphical presentations. For numeric input, the production and workforce levels were entered through the keyboard; for graphic input, data was entered by manipulating the height of the corresponding bars in the bar charts through the mouse. The cost information was shown using a second screen in which spreadsheet format was used for treatments using tabular presentation and a combined graph consisting of lines and stacked bar chart was used for treatments using graphical presentation. Figure 2(a) and (b), 3(a) and (b), and 4(a) and (b) show respectively the input and output screens of the three different user interface types.

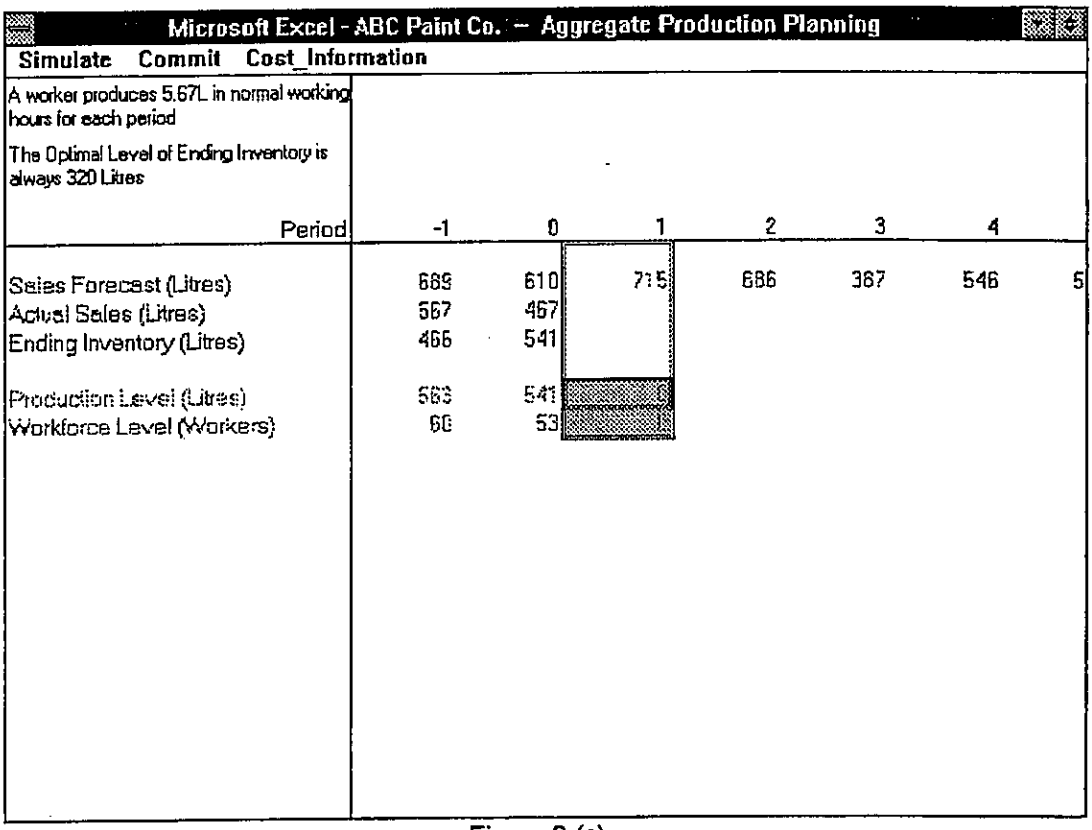

Figure 2 (a)

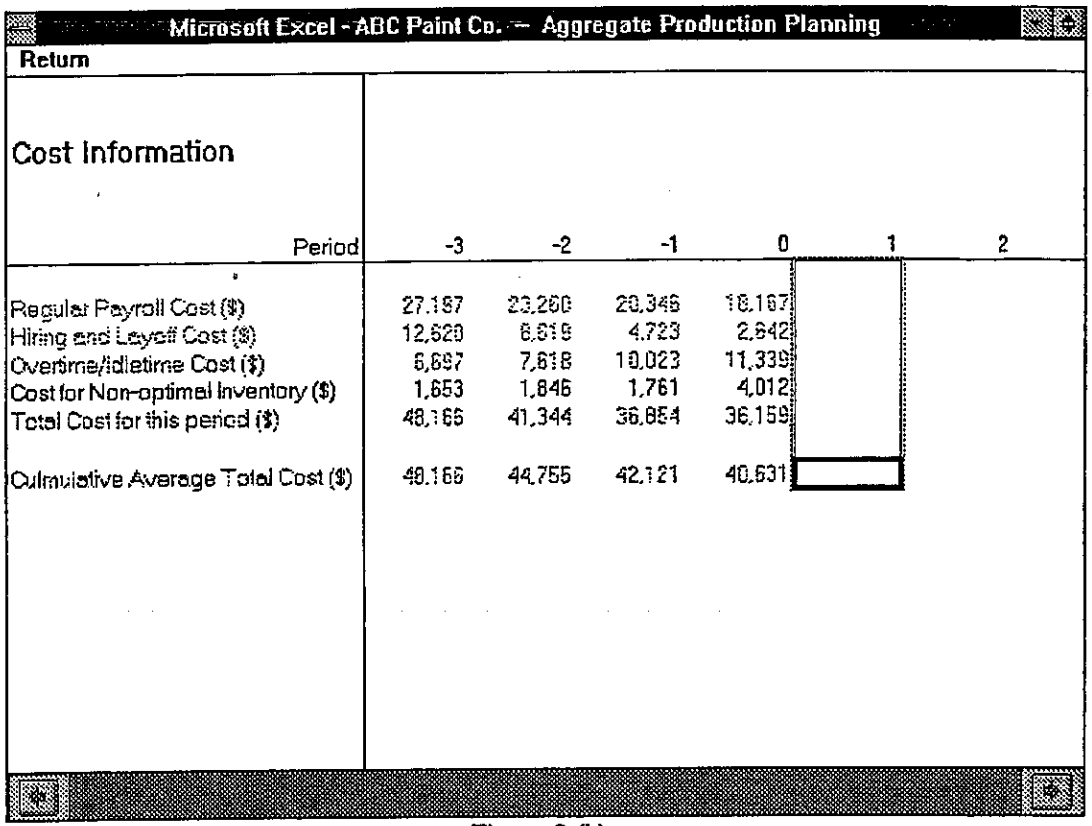

Figure 2 (b)

Figure 2 (a) & (b). Sample Screens for Decision Aid Using User Interface Type Involving Numeric Input and Tabular Presentation, with What-if Analysis

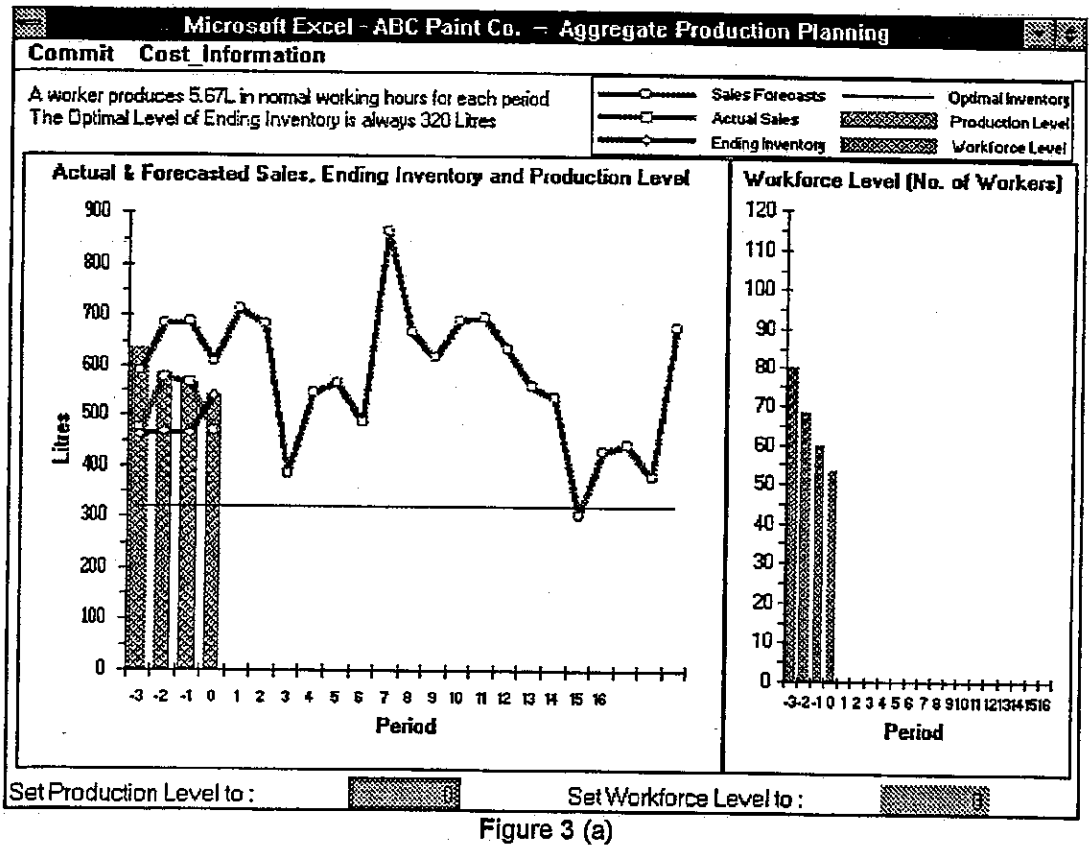

Figure 3 (a)

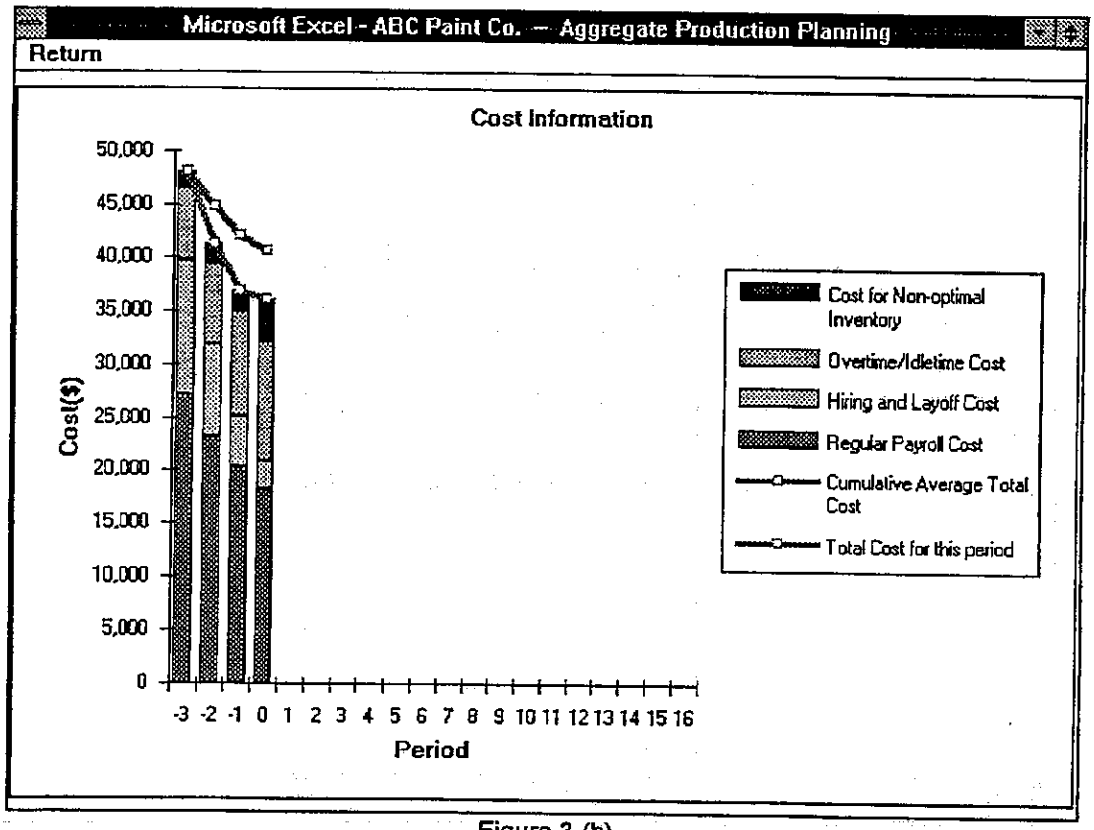

Figure 3 (b)

Figure 3 (a) & (b). Sample Screens for Decision Aid Using User Interface Type Involving Numeric Input and Graphical Presentation, without What-if Analysis

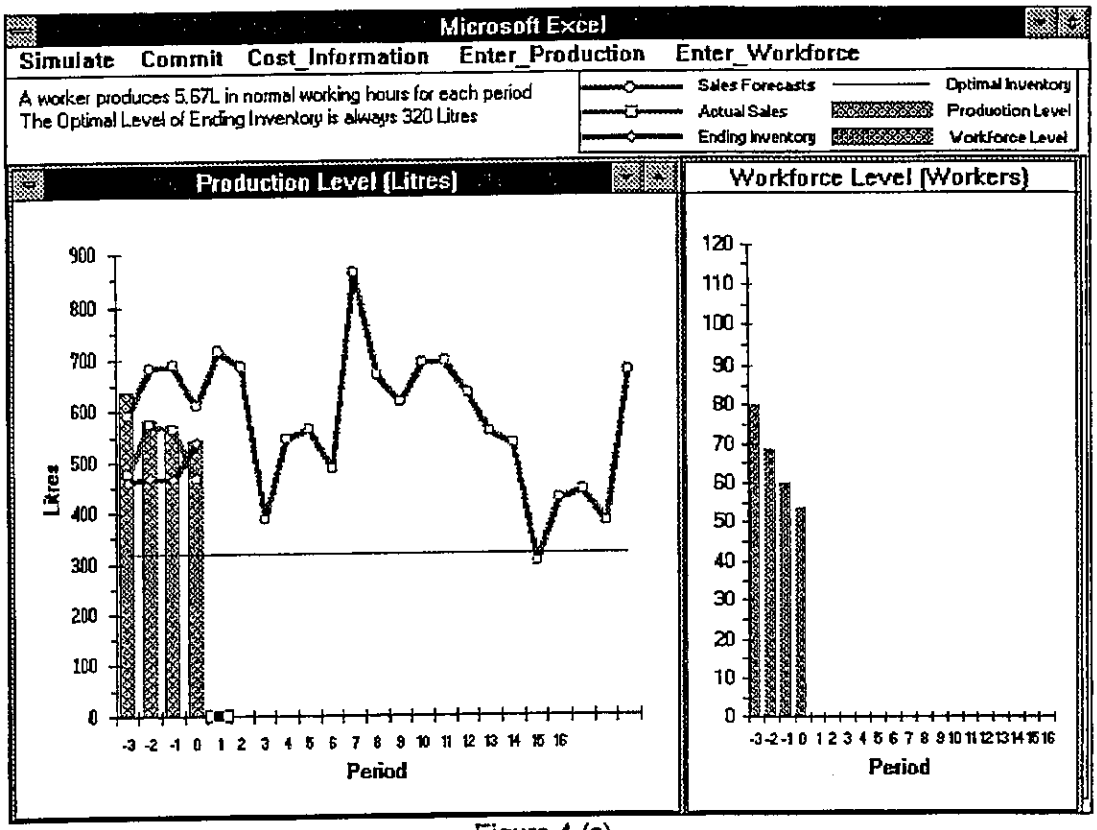

Figure 4 (a)

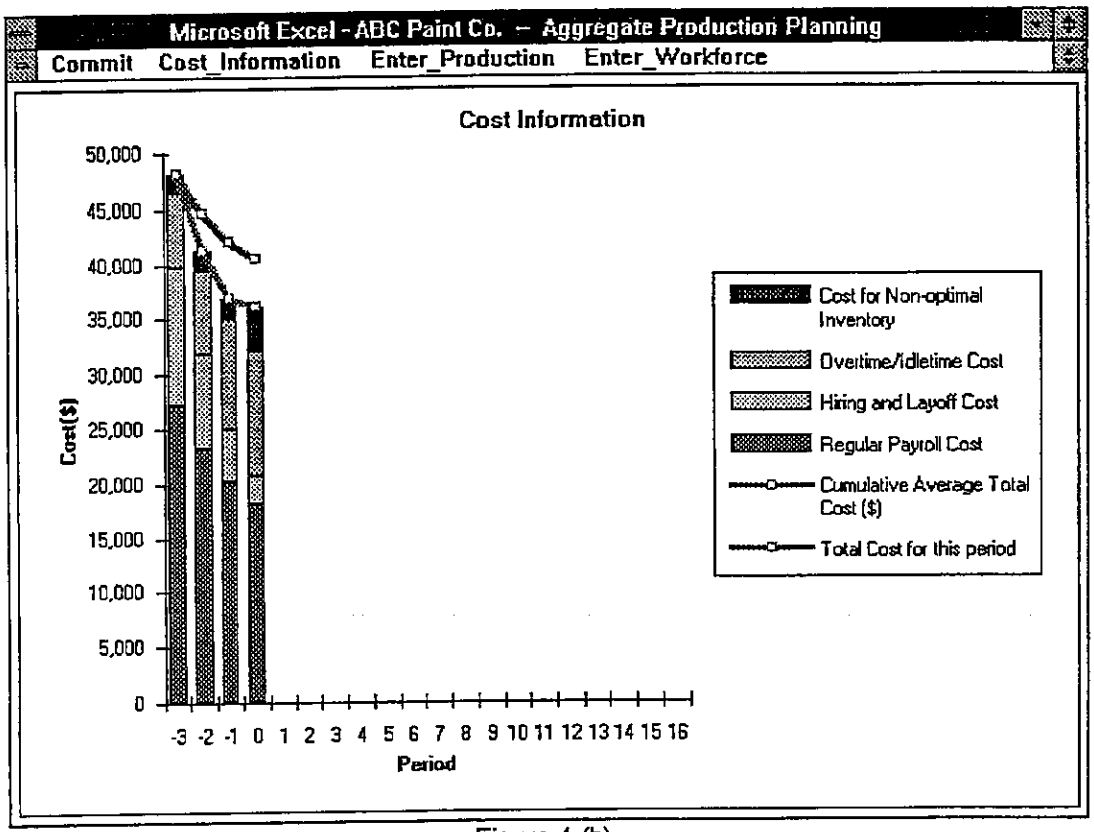

Figure 4 (b)

Figure 4 (a) & (b). Input Screen for Decision Aid Using User Interface Type Involving Graphical Input and Graphical Presentation, with What-if Analysis

In all treatments, operations of the decision aids involved choosing the appropriate commands from a command menu at the top of the screen using the mouse. After entering the production and workforce levels, subjects committed their decisions by clicking the 'commit' command. The computer system would then calculate the cost based on the cost functions in the model; the actual sales and cost components for that period would be displayed. Subjects then proceeded to the next period. For treatments with what-if analysis, a 'simulate' command was provided which allow subjects to experiment with the results of different production and workforce levels calculated based on the sales forecast (instead of actual sale) for that period before they committed their decisions for each period.

Subjects and Procedure

There were 106 subjects drawn from a sophomore Operations Management course in which the concepts of aggregate production planning were taught. They were randomly assigned to treatments. Each subject received a payment of NZ$10 for participating in the experiment. Three monetary prizes were also given to the three best performing subjects in order to motivate the subjects to perform to the best of their ability.

Subjects were given an information sheet at the time of recruitment which explained briefly the purpose and the task of the experiment. The number of subjects in each experiment session varied from one to six. The GEFT instrument was first administered. Subjects then worked individually according to the task description and a user guide for the corresponding treatment. They were given three practice periods before they worked on the 16 'actual' periods. After finishing the task, they completed a final questionnaire. Subjects were told that they could take as long as they needed to complete the task.

A pilot test was conducted two month prior to the actual experiment. This resulted in some changes in the design of the computer decision aids and the final questionnaire.

Results

The production cost obtained in each of the 16 periods and the time used to finish the task by each subject were recorded automatically by the computer decision aid the subject used. Similar to DeSanctis and Jarvenpaa (1989), a 7-point Likert scale was used to measure subjects' self-evaluated overall decision confidence in the final questionnaire. Perceived usefulness and perceived ease of use of the decision aid were each measured by a six-item scale developed by Davis (1989) in the final questionnaire. Analysis of variance (ANOVA) was performed for each dependent variable. Four outliers in production cost were excluded from the analyses of production cost and learning effects. Full results are reported below.

Production Cost

The mean production cost over the 16 periods for the six treatment groups are shown in Table 2. The treatment using the computer aid with what-if analysis and the interface type involving graphical input and graphical presentation attained the lowest production cost. ANOVA showed that both the main effect and the interaction effect were significant. Subjects using what-if analysis obtained a significantly lower production cost than subjects without using what-if analysis (α=0.005). Different user interface types also resulted in significantly different decision performance (α=0.05 level). In addition, the performance of what-if analysis was affected by the type of user interface used (interaction effect was significant at 0.05 level).

		User Interface Type			
		Numeric Input with Tabular Presentation	Numeric Input with Graphical Presentation	Graphical Input with Graphical Presentation	Marginal Mean
What-if Factor	Without What-if Analysis	49778.06	41477.42	36634.29	42975.79
	With What-if Analysis	34125.77	40572.80	31917.42	35378.38
	Marginal Mean	41951.92	40981.34	34073.70	38953.63

Table 2 Mean Production Costs of the Six Treatment Groups

The graph of interaction effect on production cost is shown in Figure 5. When the interface associated with numeric input and graphical presentation was used, there was no significant difference on production cost between the treatments using what-if analysis and the treatments without using what-if analysis. However, the performance of what-if analysis was greatly enhanced

when the other two interface types were used. This indicated that the effect of what-if analysis was indeed dependent on the type of interface used.

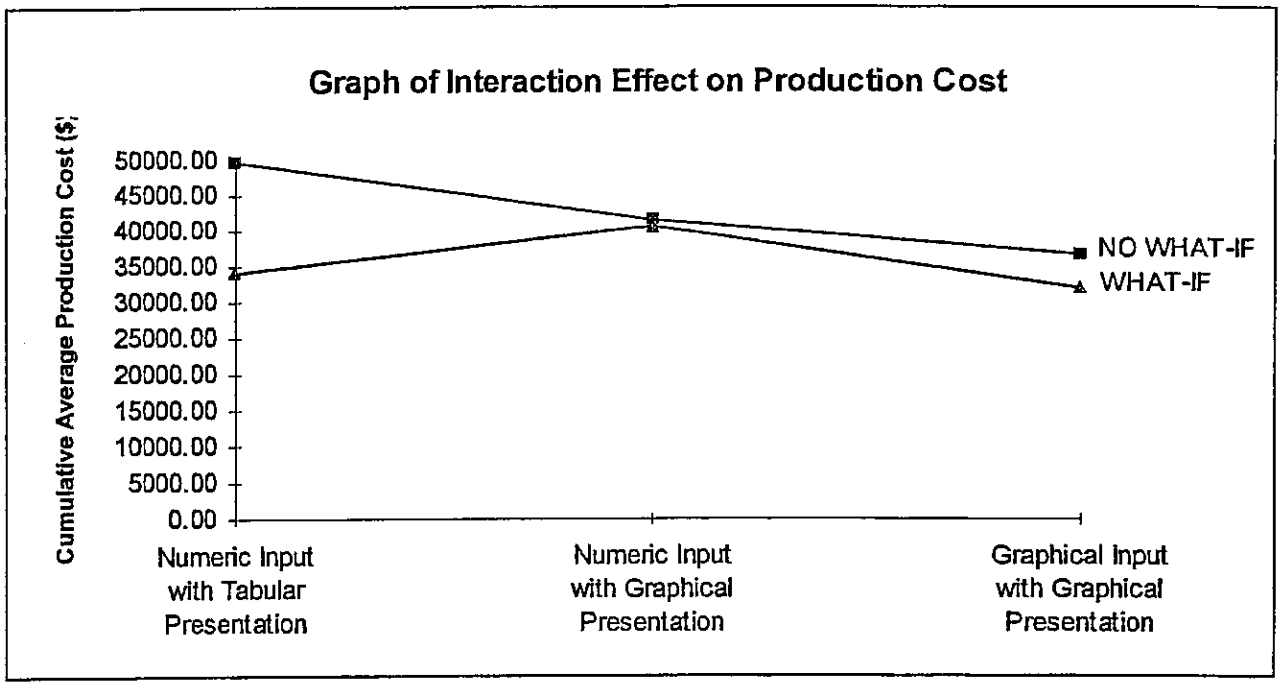

Figure 5 Graph of Interaction Effect on Production Cost

Learning Effect

Production costs obtained from the linear decision rules were used as bases to compare the change in decision performance over time (i.e. the learning effect). Adjusted cost in each period was calculated as:

$$\text{adjusted cost} = \frac{\text{production cost obtained by a subject - optimal production cost obtained using decision rules}}{\text{optimal production cost obtained using decision rules}}$$

The 16 periods were divided into 4 phases: phase 1 (periods 1-4), phase 2 (periods 5-8), phase 3 (periods 9-12) and phase 4 (periods 13-16). The mean adjusted cost in each phase was calculated. The change of mean adjusted cost from phase 1 to phase 2, from phase 2 to phase 3, and from phase 3 to phase 4 served as the measures of learning rates at three different stages, namely, early, transition, and final stage respectively. ANOVA on learning rate was performed for each of the three stages. Surprisingly, the result showed that there were no significant main and interaction effects. One possible explanation for this may be that the learning rate of this particular task was dependent on other factors such as the demand pattern and forecast accuracy.

Decision Time

Table 3 shows the decision time of the six treatment groups. The ANOVA result indicated that subjects using what-if analysis spent significantly more time than subjects without using what-if anlaysis (α=0.05). However, the effect of interface type and the interaction effect were not significant. The longer time associated with the use of what-if analysis may be attributed to the number of decision alternatives considered when subjects made their decisions.

		User Interface Type			
		Numeric Input with Tabular Presentation	Numeric Input with Graphical Presentation	Graphical Input with Graphical Presentation	Marginal Mean
What-if Factor	Without What-if Analysis	1337.06	1274.00	1280.76	1298.04
	With What-if Analysis	1739.61	1620.35	1428.53	1592.61
	Marginal Mean	1538.33	1447.18	1358.75	1448.10

Table 3 Mean Decision Time (in seconds) of the Six Treatment groups

Decision Confidence

Subjects ranked their overall decision confidence on a 7-point Likert scale (1-not confident at all; 7-very confident). The mean ranking of decision confidence for each treatment group is displayed in Table 4.

		User Interface Type			
		Numeric Input with Tabular Presentation	Numeric Input with Graphical Presentation	Graphical Input with Graphical Presentation	Marginal Mean
What-if Factor	Without What-if Analysis	3.83	3.94	3.82	3.87
	With What-if Analysis	3.94	3.82	4.66	4.16
	Marginal Mean	3.89	3.88	4.26	4.01

Table 4 Mean Rankings of Decision Confidence of the Six Treatment Groups

Overall, subjects using what-if analysis were more confident than their counterparts and the decision confidence of subjects using the interface type with graphical input and graphical presentation was higher than subjects using the other two interface types. Although these results are in the hypothesized direction, the ANOVA result indicates that both the main effect and the interaction effect were not statistically significant.

Perceived Usefulness

Perceived usefulness was measured by a six-item scale with 7-point Likert scale (1 - not useful, 7 - very useful). The perceived usefulness scales showed a reasonably high level of reliability, Cronbach alpha=0.85. The item means of the six treatment groups are shown in Table 5.

		User Interface Type			
		Numeric Input with Tabular Presentation	Numeric Input with Graphical Presentation	Graphical Input with Graphical Presentation	Marginal Mean
What-if Factor	Without What-if Analysis	5.53	5.40	5.37	5.44
	With What-if Analysis	5.41	5.63	5.93	5.66
	Marginal Mean	5.47	5.51	5.67	5.55

Table 5 Item means of Perceived Usefulness of the Six Treatment groups

As hypothesized, subjects using what-if analysis perceived the decision aid to be more useful than subjects without using what-if analysis. Also, the decision aid with the interface type involving graphical input and graphical presentation received the highest rating of perceived usefulness among the three interface types. But the ANOVA result showed that the differences were not significant and there was also no significant interaction effect.

Perceived Ease Of Use

Perceived ease of use was also measured by a six-item scale with 7-point Likert scale (1 - not easy to use, 7 - very easy to use). A high level of reliability, Cronbach alpha=0.91, was obtained. The item means of the six treatment groups are shown in Table 6.

		User Interface Type			
		Numeric Input with Tabular Presentation	Numeric Input with Graphical Presentation	Graphical Input with Graphical Presentation	Marginal Mean
What-if Factor	Without What-if Analysis	5.43	5.32	5.53	5.42
	With What-if Analysis	5.58	5.34	5.88	5.61
	Marginal Mean	5.50	5.33	5.72	5.52

Table 6 Item means of Perceived Ease of Use of the Six Treatment Groups

Subjects using what-if analysis perceived the decision aid to be easier to use than their counterparts. In addition, the decision aid with graphical input and graphical presentation received a much higher rating than the other two interface types. However, the ANOVA result showed that both the main and interaction effect were not statistically significant.

Table 7 summarizes the p-value obtained from the ANOVA of the six dependent variables.

Dependent Variables	Main Effect of What-if Factor	Main Effect of User Interface Type	Interaction Effect of the two Main Factors
Production cost	0.0022**	0.0108*	0.0233*
Learning rate	0.9935	0.4493	0.8432
Decision time	0.0026**	0.2986	0.5257
Decision confidence	0.2202	0.3272	0.1979
Perceived usefulness	0.1214	0.5391	0.1498
Perceived ease of use	0.3352	0.2574	0.7659

* significant at 0.05 level
** significant at 0.005 level

Table 7 Summary Table of ANOVA Results

Analysis Of Covariance
Analysis of covariance (ANCOVA) was performed on each dependent variables, using the GEFT scores of subjects as the covariate. Similar results as discussed above were obtained from the ANCOVA after the possible effect of divergent cognitive styles of subjects was controlled.

The results of hypothesis testing are summarized in Table 8 below:

Hypothesis	p-value	Hypothesis Supported	Description of Results
Main Effect of What-if Factor			
H1: Production cost: What-if vs no what-if	0.0022**	Yes	What-if group had a lower cost than no what-if group
H2: Learning at early stage: What-if vs no what-if	0.9935	No	What-if group has a faster learning rate than no what-if group
H3: Decision time: What-if vs no what-if	0.0026**	Yes	What-if group took longer to complete decisions in 16 periods than no what-if group
H4: Decision confidence: What-if vs no what-if	0.2202	No	What-if group had a higher decision confidence than no what-if group
H5: Perceived usefulness: What-if vs no what-if	0.1214	No	What-if group perceived the decision aids to be more useful than no what-if group
Main Effect of User Interface Type			
Production Cost:†			
H6a: Graphical input & graphical presentation vs Numeric input & graphical presentation	>0.05 without what-if; ≤0.05* with What-if	Partly	Graphical input & graphical presentation led to a lower cost than numeric input & graphical presentation
H6b: Graphical input & graphical presentation vs Numeric input & tabular presentation	≤0.05* without what-if; >0.05 with what-if	Partly	Graphical input & graphical presentation led to a lower cost than numeric input & tabular presentation
H6c: Numeric input & graphical presentation vs Numeric input & tabular presentation	>0.05	No	Without what-if, numeric input & graphical presentation led to a lower cost than numeric input & tabular presentation With what-if, numeric input & graphical presentation led to a higher cost than numeric input & tabular presentation
Learning Rate at early stage:§			
H7a: Graphical input & graphical presentation vs Numeric input & graphical presentation	0.4493	No	Graphical input & graphical presentation led to a slower learning rate than numeric input & graphical presentation
H7b: Graphical input & graphical presentation vs Numeric input & tabular presentation	0.4493	No	Graphical input & graphical presentation led to a faster learning rate than numeric input & tabular presentation
H7c: Numeric input & graphical presentation vs Numeric input & tabular presentation	0.4493	No	Numeric input & graphical presentation led to a faster learning rate than numeric input & tabular presentation
Decision Time:§			
H8a: Graphical input & graphical presentation vs Numeric input & graphical presentation	0.2986	No	Graphical input & graphical presentation needed less decision time than numeric input & graphical presentation
H8b: Graphical input & graphical presentation vs Numeric input & tabular presentation	0.2986	No	Graphical input & graphical presentation needed less decision time than numeric input & tabular presentation
H8c: Numeric input & graphical presentation vs Numeric input & tabular presentation	0.2986	No	Numeric input & graphical presentation needed less decision time than numeric input & tabular presentation

* significant at 0.05 level

** significant at 0.005 level

† only 0.05 significant level was specified in the Scheffe's test, p-value could not be obtained

§ The effect of the three user interface types on a particular dependent variable was firstly tested using ANOVA. Further comparison tests would be conducted only if the effect was significant in the ANOVA test. Therefore, if the ANOVA result was not significant for the user interface type, hypotheses pertaining the effect of user interface type on a particular dependent variable would be reported with the same p-value (obtained from the ANOVA).

Table 8 Summary Table of Hypothesis Testing

Hypothesis	p-value	Hypothesis Supported	Description of Results
Decision Confidence:§			
H9a: Graphical input & graphical presentation vs Numeric input & graphical presentation	0.3272	No	Graphical input & graphical presentation led to higher decision confidence than numeric input & graphical presentation
H9b: Graphical input & graphical presentation vs Numeric input & tabular presentation	0.3272	No	Graphical input & graphical presentation led to higher decision confidence than numeric input & tabular presentation
H9c: Numeric input & graphical presentation vs Numeric input & tabular presentation	0.3272	No	Numeric input & graphical presentation led to lower decision confidence than numeric input & tabular presentation
Perceived Usefulness:§			
H10a: Graphical input & graphical presentation vs Numeric input & graphical presentation	0.5391	No	Graphical input & graphical presentation led to greater perceived usefulness than numeric input & graphical presentation
H10b: Graphical input & graphical presentation vs Numeric input & tabular presentation	0.5391	No	Graphical input & graphical presentation led to greater perceived usefulness than numeric input & tabular presentation
H10c: Numeric input & graphical presentation vs Numeric input & tabular presentation	0.5391	No	Numeric input & graphical presentation led to greater perceived usefulness than numeric input & tabular presentation
Perceived Ease of Use:§			
H11a: Graphical input & graphical presentation vs Numeric input & graphical presentation	0.2574	No	Graphical input & graphical presentation led to greater perceived ease of use than numeric input & graphical presentation
H11b: Graphical input & graphical presentation vs Numeric input & tabular presentation	0.2574	No	Graphical input & graphical presentation led to greater perceived ease of use than numeric input & tabular presentation
H11c: Numeric input & graphical presentation vs Numeric input & tabular presentation	0.2574	No	Numeric input & graphical presentation led to less perceived ease of use than numeric input & tabular presentation
Interaction Effect on			
H12: Production Cost	0.0233*	Yes	What-if group had a lower cost than no what-if group which was significant at 0.05 & 0.001 levels when numeric input & tabular presentation and graphical input & graphical presentation were used respectively. The cost different was not significant when numeric input & graphical presentation was used.
H13: Learning rate at early stage	0.8432	No	
H14: Decision Time	0.5257	No	
H15: Decision Confidence	0.1979	No	
H16: Perceived Usefulness	0.1498	No	

* significant at 0.05 level

§ The effect of the three user interface types on a particular dependent variable was firstly tested using ANOVA. Further comparison tests would be conducted only if the effect was significant in the ANOVA test. Therefore, if the ANOVA result was not significant for the user interface type, hypotheses pertaining the effect of user interface type on a particular dependent variable would be reported with the same p-value (obtained from the ANOVA).

Table 8 (Continued) Summary Table of Hypothesis Testing

Discussion

Results from this study indicate that what-if analysis feature in DSSs contribute to statistically significant increase in decision performance but at the expense of a longer decision time. The improvement in decision may derive from the fact that what-if analysis helps to evaluate a greater number of decision alternatives and by providing decision feedback to the decision maker before the final decision is made. As more alternatives were considered, a longer time was needed. There was no direct evidence from our study of the phenomenon of 'illusion of control' reported by Davis, Kottemann and Remus (1991).

Most importantly, this study shows that the type of user interface does have significant impact on the effectiveness of a DSS. For this particular task, using the interface type with graphical input and graphical presentation resulted in better performance. This also demonstrates that besides visual appeal of graphically presented information, there may be other more tangible benefits to using GUIs.

There was also a significant interaction effect between the use of what-if analysis feature and user interface type on production cost, i.e. the performance of what-if analysis was moderated by the user interface type used. This suggests that the design of DSS in terms of its features and functionalities needs to be matched by a suitable user interface for its benefits to be realized.

Although the effects on other dependent variables were not statistically significant, the results did point to the possibility that what-if analysis contributes to higher decision confidence and was perceived to be more useful and easier to use. Similarly, using graphic input and graphic presentation also contributed to shorter decision time, higher decision confidence, greater perceived usefulness and greater perceived ease of use.

Conclusion

This study concludes that what-if analysis can lead to better decision performance in the use of DSS. The input and output user interfaces of the DSS also have a significant impact on its effectiveness. Furthermore, the effects of what-if analysis and user interface type are inter-related. Future research is needed to examine tasks with different structure and complexity, and different formats of input and output.

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